GEOLOGICAL EVALUATION OF A PART OF THE JAMBI TROUGH, SUMATRA, INDONESIA

A THESIS SUBMITTED TO THE GRADUATE SCHOOL IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE MASTER OF SCIENCE

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BALL STATE UNIVERSITY
MUNCIE, INDIANA
(DECEMBER 2013)
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>TABLE OF CONTENTS</td>
<td>I-II</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>III</td>
</tr>
<tr>
<td>ACKNOWLEDGEMENT</td>
<td>IV-V</td>
</tr>
<tr>
<td>ABSTRACT</td>
<td>VI</td>
</tr>
<tr>
<td>TABLE 1</td>
<td>54</td>
</tr>
<tr>
<td>APPENDIX</td>
<td>54-78</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>79-83</td>
</tr>
</tbody>
</table>
TABLE OF CONTENTS

Chapter 1 .................................................................................................................................................. 1

INTRODUCTION........................................................................................................................................... 1

1.1 Conceptual Background...................................................................................................................... 1

1.2 Objectives of study.............................................................................................................................. 1

1.3 Method of study.................................................................................................................................... 2

Chapter 2 .................................................................................................................................................... 5

GEOLOGIC BACKGROUND OF SUMATRA ............................................................................................. 5

2.1. The Forearc region ............................................................................................................................. 10

2.1.1 The subduction trench and the accretionary complex ................................................................. 10

2.1.2 The forearc ridge ........................................................................................................................... 11

2.2 The Barisan Mountain and the Sumatra Fault system................................................................. 13

2.2.1 The Sumatra Fault system........................................................................................................... 15

2.3. The Backarc region........................................................................................................................... 19

Chapter 3 .................................................................................................................................................... 21

GEOLOGY OF SOUTH SUMATRA BASIN ............................................................................................. 21

3.1.1 The Horst and Graben Stage ....................................................................................................... 23

3.1.2 The Transgressive and Regressive Stage .................................................................................... 23

3.2. PRODUCTION HISTORY .................................................................................................................. 24

3.2.1. The Palembang Sub-Basin ...................................................................................................... 25

3.2.2. The Jambi Sub-Basin (Jambi Trough) ..................................................................................... 26
<table>
<thead>
<tr>
<th>Chapter 4</th>
<th>SEQUENCE STRATIGRAPHY AND BASIN ANALYSIS OF SOUTH SUMATRA BASIN</th>
<th>28</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1 RESERVOIR ROCKS OF THE SOUTH SUMATRA</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>4.10 Basement Rocks</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>4.11 The Lahat Formation (also known as Lemat Formation)</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>4.12 The Talangakar Formation</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>4.13 The Baturaja Limestone</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>4.14 The Gumai Formation</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>4.15 The Airbenakat Formation</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>4.16 The Muaraenim Formation</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>4.17 The Kasai Formation</td>
<td>32</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chapter 5</th>
<th>34</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1 RESULTS</td>
<td>34</td>
</tr>
<tr>
<td>5.2 DISCUSSIONS</td>
<td>45</td>
</tr>
<tr>
<td>5.3 CONCLUSIONS</td>
<td>53</td>
</tr>
</tbody>
</table>
LIST OF FIGURES

Figure 1 shows the location of oil fields in the South Sumatra basin................................. 4
Figure 2 shows map of Sumatra from other maps of other continent.................................. 6
Figure 3 shows the area map of Sumatra and its length of extension..................................... 7
Figure 4 shows the subduction boundary of Sumatra.......................................................... 8
Figure 5 shows Sumatra from other minor and major tectonic Plates .................................. 10
Figure 6a shows the Sumatran Forearc plate and its motions................................................. 14
Figure 6b shows the Pre-Tertiary basement rocks Tertiary sediments of Sumatra .............. 15
Figure 7a shows Sumatra Fault Systems ............................................................................. 17
Figure 7b shows the sea elevation, the active volcanoes and the Sumatra Fault system ....... 18
Figure 8 shows the South Sumatra backarc basins .............................................................. 20
Figure 9 shows the structural features of the South Sumatra Basin and the Tembesi Fault.... 22
Figure 10 shows the stratigraphic column of the South Sumatra Basin ............................. 33
Figure 12 shows the isopach map of the Airbenakat Formation ........................................... 37
Figure 13 shows the isopach map of the Talangakar Formation .......................................... 38
Figure 14 shows the isopach map of the basement rock....................................................... 39
Figure 15 shows the base map/contour lines, well locations and well depths ....................... 40
Figure 17 shows the cross section of the South Sumatra basin ............................................. 42
Figure 19 shows the stratigraphy interpolation between all formations of South Sumatra Basin 44
Figure 20 shows 3D structural model and seismic interpretation of southwestern domain of
Southern Sumatra .................................................................................................................... 48
ACKNOWLEDGEMENTS

All glory and honor be unto God for the opportunity he gave me to be a student at the Department of Geological Sciences and Ball State University. I would like to acknowledge and extend my heartfelt gratitude to the following persons who have made the completion of this project a success.

A special thank you to my sponsor, Dr. Will Ade for giving me the opportunity to have access to the database and for sponsoring this project. May God continue to encourage and strengthen you.

My heartily thankful to my supervisor, Dr. Richard Fluegeman whose help, guidance and support from the beginning to the end enabled me to develop an understanding of this project, thank you for providing me with a warm atmosphere and for all the motivation.

My committee members, Dr. Kirsten Nicholson thank you for the inspiration and care. To Dr. Jeffrey Grigsby, thank you for all your help and support both directly and indirectly. To the departmental chairperson Dr. Rice-Snow, thank you for all the support and for having me in your department.

Lastly, many thanks to every other faculty members, Dr. Newmann, Dr. Dowling, Dr. Weng, Mr. Betz, Mrs. Rathel, Mike Kutis, my other graduate students and my undergraduate friends (Austin York and Michele Murday) who have helped me in several ways and have contributed in many ways to my graduate program at Ball State University. I am happy that I have completed my studies but at the same time I am sad because I am leaving my family whom have impacted my life in so many ways. Really, words alone can’t express how much I appreciate everyone that has made my studies and stay at Ball State University a memorable one.
To my family whose continuous and endless calls have pushed and pulled me to the end of my graduate program at Ball State University, thank you all for believing in me. I am thankful to everyone for having me in the department, may God continue to guard and guide you all.
ABSTRACT

THESIS: Geological Evaluation of a Part of the Jambi Trough, Sumatra, Indonesia

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DEGREE: Master of Science

COLLEGE: Sciences and Humanities

DATE: December, 2013

PAGES: 83

The research involves mapping of subsurface at a scale of 1:25,000 the top of three geological formations in the Southern Part of Sumatra – the Airbenakat Formation, the top of the Talangakar Formation, and the top of structural basement in the Jambi Trough. Isopach maps of the formations will be constructed. These maps will form the basis of a basin analysis and hydrocarbon source rock assessment of the Jambi Trough using Basin Mod basin modeling software (Rockworks Software).

The studies utilize the L. Bogue Hunt Southeast Asia database housed in the Department of Geological Sciences at Ball State University. Seismic record sections, geophysical logs, cutting descriptions, and paleontological reports will provide basic geological data to enable mapping of the three horizons.

Although hydrocarbon accumulations are abundant in Central and Southern Sumatra, the nature of the source rocks is only partially understood. The proposed research will map the Airbenakat and Talangakar Formations while identifying the areas of thermally mature source rock is the main goal of the research. This study will identify characteristics which will enable the identification of thermally mature rocks in other regions of Sumatra.

The area of the project is located at the Southeastern part of Asia in Indonesia and mainly the Jambi trough located in Southern Sumatra. Generally, the geology and tectonics of this area (Sumatra) is controlled by the subduction of the Indian plate towards the east and beneath the Eurasia plate.
Chapter 1

INTRODUCTION

1.1 CONCEPTUAL BACKGROUND

This project mapped the subsurface of the top of two geological formations and the basement rock in the onshore area of the South Sumatra basin – the Airbenakat Formation, the top of the Talangakar Formation and the basement rock; generally all the formation tops and the structural basement in the Jambi Trough were mapped at a scale of 1:25,000. These formations were mapped to see if there was a correlation between the depth of basement and the distribution of oil production in South Sumatra, of particular interest to this project is the Jambi Trough located at the northern part of the South Sumatra basin of the back arc region. The project looked at four hundred and ten wells (examples of wells are Sekamis 1, Tambesi bay 1, Meruap 4, Meruap 1, Meruap 3, Terap 1, Menggala Selatan 1, Ratu 1, etc.) at different fields (fields like Wildcat, Kuang, Limau, Lubak Rukum, etc.) in the Southern Sumatra basin (the South Sumatra basin is divided into two sub-basins, the Jambi sub-basin and the Palembang sub-basin). Figure 1 shows the locations of oil fields in the Southern Sumatra basin province.

The backarc regions of Sumatra and other Southeast Asia have been proven to be rich in oil and gas and this makes it an important area for oil and gas exploration. Generally, the same geological process that has affected this area (Sumatra) is also noticed in some other basins of the Southeast Asia.

1.2 OBJECTIVES OF THE STUDY

With the development of sedimentary basins at the backarc region of Sumatra, and the filling of these basins during the Tertiary by sediments rich in organic components, the area has been
found to be very rich in oil and gas. Most of the oil and gas in Sumatra are located at the backarc region, which are prospect areas being explored by many oil companies.

This project is important because it will provide an insight in studying how hydrocarbons have accumulated at this region and because the Jambi Trough is a recent spot for oil and gas exploration in Sumatra. Isopach maps, base map, stratigraphy map and structural map of these wells will be constructed to help in identifying the relationships and link between all the formations in the South Sumatra basin.

The main goal of this project is to investigate the relationship between the depth of basement and distribution of oil production, and if there are no relationship suggestions and controls on oil production and distribution will be evaluated.

1.3 METHOD OF STUDY

The methods involved analyzing well log data by identifying all formation tops and bases that is subtracting individual formation depth from total driller elevation of all formations on each of the well logs, and then using the Rockworks Software to construct maps e.g. stratigraphy maps of all formations and using the Surfer 11 Software to construct isopach maps. The major formations of interest are the Airbenakat Formation, the Talangakar Formation and the basement rock. The four hundred and ten sonic logs that were analyzed provided information for each well that included the longitude, latitude, total driller depth and the ground level elevations of all the formations. Though not all wells may be oil producers this information provides a guide in the structural production and development of oil and gas in this study area. Geological well log data, cutting descriptions, geology of formations, types and environment of deposition of sediments, sequence stratigraphy, stratigraphy and paleontological reports provide other useful information about this area and all it formations. Of great importance to this project from the well logs
provided are the longitude, latitude, total depth driller, the ground level elevation, depth to the
top and base of each formation. The plot of the longitude and latitude of the wells using the
Rockworks Software helped in identifying the locations of the wells, the depth to top and base
helped in visualizing the formation contacts in the 3D Stratigraphy/Isopach maps of all
formations. Examples of the well logs that were looked at are shown in the appendix section of
this project.
Figure 1 shows the location of oil fields in the South Sumatra basin. From Bishop, 2001.
Chapter 2

GEOLOGIC BACKGROUND OF SUMATRA

The country of Indonesia is located at the Southeastern part of Asia; it has the largest island and the fifth largest in the world – Sumatra (Barber et al., 2005). Figure 2 shows the location of Sumatra on a world map. This region of Indonesia (Sumatra) has an area of about 473,606km$^2$. It extends from northwest (Simeulue) to southeast (Pagai) about 1760km, and across from west to east about 400km extending from Bangka and Billiton to the Riau Island. Figure 3 shows the area map of Sumatra and it length of extension (Barber et al., 2005). Its boundary countries are Australia, Malaysia, Sri Lanka and China. The Sumatra region has been described tectonically and geologically based on its structural and tectonic forms (Figure 4 shows the subduction boundary of Sumatra). Van Bemmelen (1949) and Hamilton (1979) have described Sumatra based on the structure and on the movement of the tectonic plates surrounding it that is based on the features and the effect of the subduction of the Indian Ocean beneath it. The Sumatra structural form is surrounded and influenced by the consequences of this subducting Indian oceanic plate as it moves underneath the Eurasia plate as both collided and converged with one another. In Barber et al., (2005), the backarc region of Sumatra has been divided into the North Sumatra Basin, Central Sumatra Basin and South Sumatra Basin based on their origin, the filling of the sedimentary basins and the quantity of oil and gas they hold for commercial purpose (Clure, 1991).
Figure 2 shows map of Sumatra from other maps of other continent. From Bishop (1988).
Figure 3 shows the area map of Sumatra and its length of extension. From Barber et al., (2005).
Figure 4 shows the subduction boundary of Sumatra. From McCaffrey (2009).
Tectonically, Hamilton (1979) has described Sumatra as an “active Andean” (Andean because of the length of extension of the mountain range) type of continental margin that forms the active southwestern margin of the Sundaland; he added that Sumatra is an active deforming region that is seismically active until present day. It is active as it is the point of collision between the Indian Oceanic Plate and forms the southeastern convergent boundary of the Eurasia Plate.

Sumatra was described geologically by Van Bemmelen (1949) as the southwestern margin of the Sundaland, which is based on its extension towards the east of the Malaysia Peninsular and towards the west of Borneo. Figure 5 shows Sumatra from other minor and major tectonic Plates. Clure (1991) has divided the backarc region of Sumatra into North, Central and South Sumatra Basins according to the sedimentary basins and their origin, but Van Bemmelen (1949) has divided the structure of Sumatra into three based on the processes surrounding their geological and structural forms. He has classified it into the Forearc region, the Barisan Mountains and the Sumatran Fault System, and the Backarc region.
Figure 5 shows Sumatra from other minor and major tectonic Plates. From Curray et al., (1979).

2.1. The Forearc region: (is the region located between a subduction zone and the volcanic chain – volcanic arc (http://earthquake.usgs.gov)). The forearc region has the following features:

2.1.1 The subduction trench and the accretionary complex: At this region is a submarine volcanic structure (the Ninety East Ridge and the Investigator Ridge) that extends from the north
to the south; it was said to form the “back bone” of the forearc region due to the transform fault of the Indian Oceanic crust, it is Cretaceous to Eocene in age (e.g. Scalter and Fisher, 1974). This region stretches to the eastern part of Indonesia from Myanmar and also forms part of the Sunda Trench. The depth of the subduction trench is about 4000km at the northern part of Sumatra and it deepens to over 6000km as it moves closer to the southern part. Its length of extension is about 250km due southwest of the mainland and about 100km due southwest of the outer arc island (Moore et al., 1982). The Nicobar fan and Bengal fan located at the eastern part and northern part of Sumatra respectively formed by accumulation of turbidites has varying thicknesses for both fans (Karig et al., 1980). The accretionary complex (also known as accretionary wedge) of the Forearc region of Sumatra consists of sediments scraped from the ocean floors. The ocean floors of the forearc region is covered by lots of sediment fans from the accretionary complex and as the plate is been subducted, it resulted in the “trenchward” movement and normal fault of the ocean floor thereby preventing sediments from the floors of the subduction trench (Karig et al., 1980). The toe of the accretionary complex is filled with sediment formed from fold (anticline) structures that is due to the uplift of the oceanic crust with evidence seen on the island of Nias (Karig et al., 1980).

2.1.2 The forearc ridge – This part forms the Forearc Island as it rises above the sea level (Indian Ocean), sedimentary sub-basins found at the forearc ridge have been related to “syn-depositional extensional faults” that were deposited at the same time as the faults formed at the accretionary complex. The effect of the subduction is noticed in basins located at the western part of Nias as it was being “infilled” during the Early Miocene and after the occurrence of inversion processes (the inversion process is one of the major tectonic phases that resulted in the formation of the South Sumatra basin e.g. Suhendan, 1984). The rate of subsidence in the Mid-
Early Pliocene is also a result from the inversion processes that caused the deformation that was noticed in most parts and particularly during the Pliocene time (Barber and Crow, 2005). Also, the oblique subduction of the Indian Ocean has not only affected the subsidence, the upliftment and compaction at the sedimentary basin, but it has also caused the subduction, strike-slip shear, shorten (transpression) and lengthen (extension) along a steep fault (transcurrent fault) (Barber and Crow, 2005). According to researchers e.g. Matson and Moore (1992), the Sumatra forearc formation is based on evidence seen from sequence stratigraphy. The sediments were formed from the increased sediments from the Nicobar fan during the late Mid-Miocene that resulted in the subsidence (depression) of the forearc ridge and the sedimentary basins. Evidence from the mode of formation of the forearc ridge has been given by different researchers but some evidence is seen in samples of large body of rocks (mélange) as they contain oceanic crust. Although, the presence of garnet amphibolites and barroisite schist clast in the samples gave another insight into the mode of formation of the forearc ridge and as reported by Moore et al., (1980). In Samuel et al., (1995)’s report he mentioned that the evidence of the mode of formation of the forearc ridge is seen in the Oligocene and Lower Miocene sandstones and conglomerates in Nias as they contain round features of quartzose and metamorphic clast which suggest that they were formed, eroded and raised from the continental margin.

2.1.3 The forearc basin – The Sumatra forearc basin lies between the forearc islands and the mainland of Sumatra and is formed between the accretionary wedge and the volcanic arc. It extends from the north to the south and includes the following basins – the Aceh Basin, the Meulaboh (also known as Simeulue) Basin, the Nias Basin, and the Mentawai and Enggano Basin. The Sumatra Basins are non-symmetrical as their depth and dip angles varies (Karig et al., 1979). Seismic sections gave an overview of the ages of the sediments from Paleogene to Present
age (Karig et al., 1979). The history of the deposition at the Forearc basin was dated from Upper-Middle and Late Miocene and differs in each basin (e.g. McCann and Habermann, 1989). It formed from sediments of turbidity currents that were deposited in deep water and covered by Pleistocene and past reefs (e.g. McCann and Habermann, 1989). The history of formation of the basins were generally related to the upliftment at the forearc as the Indian Oceanic spreading ridge and the Investigator ridge subducted beneath the forearc (e.g. McCann and Habermann, 1989).

2.2 The Barisan Mountain and the Sumatra Fault system: In Barber et al., (2005)’s report, the Barisan Mountain was described as the “Backbone” of the main land of Sumatra. This part contains sedimentary and volcanic rocks that have been changed metamorphically. Its area of extension is from the north (the Banda Aceh) to Bandar Lampung at the south with a parallel length of extension of about 1700km (Barber and Crow, 2005). The mountain ranges here rise from 3000m in Banda Aceh to about 3805m in Gurung Kerinci at the Centre, with its width about 100km close to the north and 50km as its becomes narrower and closer to the southern part. The basement of the mountain ranges at the northern part of Sumatra formed from rocks of the Pre-Tertiary of Carboniferous to Cretaceous age and were later covered by Tertiary sedimentary and volcanic rocks while the basement rock at the southern part were formed from Tertiary rocks of past sediments and volcanic rocks with some seismically active volcanoes and some alternating sediment layers of Late Pleistocene to recent volcanoes (Barber and Crow, 2003). Figure 6a shows the Sumatran forearc plate and its motion and Figure 6b shows the structural map with the Pre-Tertiary basement rocks, the Tertiary sediments and volcanics that formed the mountain ranges of Sumatra, the forearc basins, and the back arc basins with their features.
Figure 6a shows the Sumatran Forearc plate and its motions. From McCffrey (2009).
Figure 6b shows the Pre-Tertiary basement rocks Tertiary sediments of Sumatra. From Barber and Crow, (2003).

2.2.1 The Sumatra Fault system: According to Milsom (2005)’s report, the tectonics of Sumatra is controlled by three major faults which runs from the Banda Aceh to the Sunda Strait, that is from Northwest to Southwest Sumatra. The “dextral transcurrent fault system” was said to have been the cause of the difference in length of the Barisan Mountain Range. The transform fault is
said to be active and its length of extension as mentioned in Barber and Crow (2005) is about 1900km forming a shape described as “a lazy S”. The fault was traced to or was mentioned to have formed during the spreading of the Andaman Sea with the age being an issue because it is not very clear but was said to be Mid-Miocene (e.g. Curray, et al., 1979), figures 7a and 7b shows the Sumatra fault system, the movements and the active volcanoes. The faults and its splits could be traced to the forearc and backarc region which have formed lakes that may have been filled by sediments during the Quaternary (Barber and Crow, 2003). The exposure of mylonite in some areas of the fault gave another overview that the fault may have “initiated” earlier than it was mentioned (McCarthy, 1997).
Figure 7a shows Sumatra Fault Systems. From Barber and Crow, (2005).
Figure 7b shows the elevation above and below sea level, the active volcanoes and the Sumatra Fault system. From McCaffrey (2009).
2.3. **The Backarc region:** This region extends from east of the Barisan Mountains to the Malacca Straits (Barber and Crow, 2003). The backarc region is known as an area of depression because it is opposite to the subduction zone and traps sediments from the volcanic arc. The backarc region has been divided into the North Sumatra Basin, Central Sumatra Basin and the South Sumatra Basin by two arches (the Ashan and the Tigapuluh arches) and also based on their sedimentary structures and accumulations during and after the rifting stages (Barber and Crow, 2003). Most of the formations in the backarc region of the basin (North Sumatra Basin, Central Sumatra Basin and the South Sumatra Basins) are composed of Tertiary sediments that were deposited during rifting and subsidence stages in Sumatra (Barber and Crow, 2003). The Backarc region is the zone that contains the major coals and the major hydrocarbons in Sumatra, the project’s area of study is Southern Sumatra Basin where the Palembang sub-basin and Jambi sub-basin (Jambi Trough) are located.
Figure 8 shows the South Sumatra backarc basins. From Darman and Sidi, (2000).
Chapter 3

GEOLOGY OF SOUTH SUMATRA BASIN

The South Sumatra Basin is separated from the Central Sumatra Basin by the Tigapuluh High. To the east the Lampung High separates it from the Sunda Basin at the Java Sea. The basin was formed by the extension of “Pre-Tertiary basement” rocks on “pre-existing faults” and the subsiding graben in the Late Eocene to Early Oligocene (Barber and Crow, 2003). In Williams et al (1995), the South Sumatra Basin has been divided into five sub-basins as follows: Jambi Sub-Basin, North Palembang, Central Palembang, South Palembang and the Bandar Jaya Basin but in Clure (1991), it was divided into two – the Palembang sub-basin and the Jambi sub-Basin; though this project will focus on the sub division by Clure (1991). Three tectonic events have formed the South Sumatra basin – 1) the Paleocene to early Miocene extension grabens, which trend in a north direction and was later filled with sediments of Eocene to early Miocene, 2) the inactive late Miocene to early Pliocene normal fault, and 3) the Pliocene to Present compression of the basement rocks with the inversion of basin and reverse normal faults that formed anticline related oil traps (Suhendan, 1984). Generally, the South Sumatra Basin consists of “semi-connected NNW-SSE trending synrift basins” (i.e. the Jambi sub-basin and the Palembang sub-basin). The smaller and proximal of the two is the Jambi sub-basin while the larger and deeper is the Palembang sub-basin (Doust and Noble, 2008). Figure 9 shows the two basins (the Jamb sub-basin and the Palembang sub-basin), and the basement faults and anticlines. This region has also being divided according to the stacking patterns “tectonostratigraphy” (the pre-rift, the Horst and Graben stage and the transgression and regression stage) of the Tertiary sediment that filled the basins (e.g. De Smet, 1992; Barber, 2000). The tectonostratigraphy stages will be discussed in the following section.
Figure 9. The structural features of the South Sumatra Basin – the Jambi Sub-basin, the Palembang Sub-basins and the Tembesi Fault. (From e.g. Hutchison, 1996).
3.1.0 The Pre-Rift Stage: The presence of this stage as mentioned in Van Bemmelen (1949) is recorded in the deposition of sediments of Nummulitic limestone on the margins of the Bengkulu Basin, though Cole and Crittenden (1997) mentioned in their reports that the Tertiary sediments of the South Sumatra Basin were derived locally from erosion of continental sediments.

3.1.1 The Horst and Graben Stage: The sediments of the horst and graben stage are represented by the Lahat Formation (also called the Lemat Formation). It includes breccias, conglomerates, and interbedded greenish-grey sandstones with some layers of volcanic rocks at the basin margins. These sediments were deposited through fast moving streams, rivers and lakes onto faults areas and areas of low topography (e.g. Courteney et al, 1990). The features of the horst and graben stage of the South Sumatra are similar to those of the Pematang Formation of the Central Sumatra (e.g. Hutapea, 1981). Also seen in boreholes of the central part of South Sumatra basins are siltstones with tuffaceous shale (e.g. Widianto and Muskin, 1989). In De Coster (1974)’s description of Lahat Formation, which he called the Lemat Formation, he described it as pieces of rocks composed of breccia, conglomerates, sandstones and a composition of interbedded fine grained Benakat Member with greyish-brown shales, tuffaceous shales, siltstones and sandstones with thin coals and uneven carbonate bands and “glauconitic units”.

3.1.2 The Transgressive and Regressive Stage: This period is witnessed by fluvial transportation when the rate of subsidence became more pronounced at the backarc region but with the rate of sediments deposited on basement rocks higher than the rate of subsidence and the infilling of the basins. The sediments deposited at this stage are seen in the Talangakar Formation, the Baturaja Formation and the Gumai Formation (De Smet, 1992; Barber, 2000); these formations will be discussed in later chapters. Marine transgressions in South Sumatra
occurred during the deposition of younger layers onlapping onto the basement rocks with the deposition of fragments of clastic rock on basement rocks and with the formation of carbonate platforms and structures which have grown organically on high fault related blocks “carbonate build-ups” (e.g. Sitompul et al, 1992; Cole and Crittenden, 1997). Maximum marine transgression took place in Mid-Miocene resulting in the deposition of the Gumai Shale Formation stratigraphically above the Talangakar Formation, acting as a seal (Courteney et al, 1990).

According to Gorsel (2011), the North, Central and South Sumatra basins have been classified as “prolific hydrocarbon-bearing basins” as oil and gas fields are “spotty” and can be found within or approximately around 50km from rift basin with Oligocene lacustrine and some coals of syn-rift source rocks.

3.2. PRODUCTION HISTORY

Three Oil seeps were first reported in South Sumatra Basin in 1866 near Muara Enim towards the east of Karangradja and were first seen by Granberg (Courteney et al 1990). The two of these seeps were later described by Strief in 1877 but the first oil discovery was in 1896 by the Muara Enim Petroleum on the Kampong Minyak Anticlinorium. The oil was located and concentrated in three broad anticline areas of South Sumatra Basin (the Muaraenim Anticlinorium, the Pendopo-Limau Anticlinorium and the Kampong-Minyak Anticlinorium (Clure, 2005)). These anticlinal structures were found where the tertiary sediments are thickest in the central part of the South Sumatra Basin (De Coster, 1974). The Kampong Minyak field has been producing for over 100 years producing about 15 million barrels of oil (Clure, 2005). Although several other oil fields were found, the most important and the largest of all was discovered in 1922. The overall largest of the oil fields were found on the Pendopo Limau
Anticlinorium (Clure, 2005). The hydrocarbons in South Sumatra are derived from the lacustrine source rock of the Lahat Formation and the terrestrial coal and coaly shale of the Talangakar Formation (e.g. Sladen, 1997). The petroleum system of the South Sumatra Basin was divided into four petroleum “subsystems” in Doust and Noble (2008)’s report.

These include:

1. The Talang Akar/ Palembang petroleum system, which is located in the Jambi and Merangan Sub-basin and contains oil and gas that accumulated during the late postrift stage.
2. The Gumai petroleum system is a single gas field of postrift period. It is located in the Jambi Sub-basin.
3. The largest oil and gas field of the Talang Akar petroleum system is located in the Palembang Sub-basin and it is composed of late synrift Talang Akar Formation and early postrift Batu Raja Formations.
4. The smaller oil field of the postrift stage of the Talang Akar/ Palembang petroleum system is located in the Muara Enim area.

3.2.1. THE PALEMBANG SUB-BASIN

The Palembang sub-basin is located at the southern part of the South Sumatra basin. It is a larger and deeper basin than the Jambi sub-basin (Doust and Noble, 2008) and is oriented in a north – south direction (Clure, 1991). The Lahat Formation, which is the earliest rifting stage, has not been penetrated in the Jambi Sub-Basin. This may be related to the basement high and the depth at the Jambi Sub-Basin (Clure, 1991). In the Palembang Sub-Basin, the Baturaja Formation forms along the coastal shelf, which is widest to the south of the basin. The shales of the Gumai Formation in the Palembang Sub-Basin form an effective regional seal than the Jambi Sub-Basin
(Clure, 1991). The central part of this basin is greater than 4km deep. At the southern part of the basin the sediments are at a depth of about 5km (Barber and Crow, 2005).

3.2.2. JAMBI SUB-BASIN (JAMBI TROUGH)

The Jambi Trough (Jambi Sub-Basin) is oriented in a NE – SW direction. It is smaller and more proximal to the source than the Palembang Sub-Basin (Doust and Noble, 2008). It has an area of many faults that are closely spaced (fault zones) called – the Tembesi Fault (figure 9). The Tembesi fault trends in a southwest to northeast direction and also forms the northwest edge of the Jambi Trough (e.g. Van Bemmelen, 1949; Hutchison, 1996). The Lahat Formation, which depicts the occurrence of the Rifting Stage, is absent in the Jambi Sub-basin even though it is present in the Palembang Sub-basin (Clure, 1991). The Lahat Formation could not be penetrated in the Jambi Sub-basin because the Lahat Formation is absent on basement highs. Also because the Jambi Sub-Basin is located up north while the Palembang Sub-basin is located down south and some grabens have not been drilled below the Talang Akar Formation (Clure, 1991). The Jambi Sub-basin is younger than the Palembang Sub-basin and both trend in different directions (the Jambi Sub-basin trends northeast-southwest while the Palembang Sub-basin trends in a north-south direction) (Clure, 1991). The Baturaja Formation (carbonate build-ups) is formed on “basement highs” along the coastal shelf of the Sunda Shelf during the transgression stage in this basin. This makes the coastal shelf more “narrower” moving upward towards the Jambi Sub-basin and thus thins out towards the Jambi Sub-basin which is unlike the Palembang Sub-Basin (Clure, 1991). The Baturaja Formation was later sealed by the Shales of the Gumai Formation because it forms a regional seal which is more pronounced at the Palembang Sub-basin than the Jambi Sub-basin (Clure, 1991). The recent discovery of oil and gas at the Jambi depression (the Jambi sub-basin) may be a proof that there may be a relationship between oil distribution and
production because the depression was said to have formed during the tectonic inversion and onset or reactivation of compression in the South Sumatra Basin in the early Miocene (Pulunggono, 1986). It has been related to the renewal of the subduction of the Indian Plate beneath the west Sumatra (Pulunggono, 1986).

Generally, the Horst and Graben Stage has played a major role in hydrocarbon accumulation at the backarc region of Sumatra because it marks the development of basins at the backarc region. At this stage the rate of subsidence was more pronounced and resulted in deposition and storage of rich and thick organic lake and paralic deposits with “sedimentologically immature sediments” along the shorelines, the thickness of the organic and paralic deposits is said to be due to lack of oxygen circulation at the bottom of the lake (De Smet, 1992; Barber, 2000).
Chapter 4
SEQUENCE STRATIGRAPHY AND BASIN ANALYSIS OF THE SOUTH SUMATRA BASIN

The South Sumatra Basin is one of many Tertiary basins in Indonesia, all of which share the same characteristics as they all pass through the four tectonostratigraphy stages - the Pre- Rift Stage, the Horst and Graben Stage, the Transgressive Stage and Regressive Stage (Doust and Noble, 2008). Sequence stratigraphy, defined as “the subdivision of sedimentary basins into genetic packages bounded by unconformities and their correlative conformities”. The sequence of event of all the formations (Basement rock, Lahat Formation, Talangakar Formation, Baturaja Limestone, Gumai Formation, Airbenakat Formation, Muaraenim Formation and Kasai Formation) in South Sumatra differs as all formations where deposited in different environmental settings and in response to different changes in sea level.

The Basement rock in South Sumatra basin is composed of volcanic rocks, this rock composition differs from all other formations in the basin because it consist of igneous rocks (e.g. Sardjito et al, 1991). Some of these rocks have undergone some changes to quartzite (e.g. Sardjito et al, 1991). Lying unconformably above these igneous rocks are sediments of the Lahat Formation, which was deposited during the Middle Eocene-Upper Oligocene and is composed of volcanic and rift sediments.

The Talangakar Formation was deposited on the Lahat Formation during the early Transgressive Stage (Spruyt, 1956). The environment of deposition range from fluvial and lacustrine to lagoonal and to shallow marine (Spruyt, 1956). The Talangakar Formation contains channeled greyish-brown sandstones, siltstones and shales that grades basinward into light brown carbonaceous shales and coal seams. The grain size varies from conglomerates to sandstone, mica is also seen in this formations. Also present in this formation are pyrite, silicified wood and
molluscs (Spruyt, 1956). The late Transgressive Stage is represented by marine sediments of the Baturaja Limestones and the Gumai Formation (Spruyt, 1956). The Gumai Formation downlaps unto the underlying reservoir rock thus allowing the flow of hydrocarbons downward into other Formation (Clure, 1991). The regressive Stage is marked by the deposition of the Airbenakat Formation, the Muaraenim Formation and the Kasai Formation (Spruyt, 1956). The environment of deposition of the Airbenakat Formation is deep marine to shallow marine and contains sediments of clays with layers of interbedded sandstones. The environment of deposition of the Muaraenim Formation is coastal and sediment composition includes sandstones with coal seams. The Kasai Formation was deposited in a terrestrial environment and includes sandstones, shales and some volcanic “debris” (Spruyt, 1956). All these formation will be described further in the following section.

4.1 RESERVOIR ROCKS OF THE SOUTH SUMATRA

For rocks to be an “economically viable petroleum reservoir” it must be porous and permeable (Gluyas and Swarbrick, 2004). Petroleum in Sumatra is controlled by plate tectonic movement as the earth crust becomes thinner after it had stretched and together with high geothermal gradient makes it possible for it to produce hydrocarbons (Clure, 1991). This however may be the reasons the backarc region of Sumatra have lots of hydrocarbons, the forearc region on the other hand has low thermal gradient and the crust is thicker due to the effect of the subduction and thus has less hydrocarbons than the backarc region (Clure, 1991). A reservoir rock is a place where oil migrates to and is held underground. Reservoir rocks are mostly sandstones and carbonates and coarse in texture with varying internal properties (porosity and permeability) (Gluyas and Swarbrick, 2004). The reservoir rocks in South Sumatra include the following: the basement rocks, the Lahat Formation, the Talang Akar Formation, the Baturaja
Limestone, the Gumai Formation, the Air Benakat Formation, the Muara Enim Formation and the Kasai Formation, figure 10 shows the stratigraphy column of the formations of the two sub-basins of the South Sumatra (e.g. Surdamono et al., 1997). The formations are as follows from the oldest to the youngest.

4.10 Basement Rocks: The basement rocks in the South Sumatra are Mesozoic and Eocene in age, it comprises of granite, some traces of quartzite and schist has shown below in figure 17 of chapter 5 (the presence of quartzite may be due to the heating and pressure during tectonic compression in the basement rock) with porosity of about 7% (Sardjito et al., 1991). The basement rock shows some form of weathering and erosion as there is an unconformity between this rock and the overlying Lahat Formation.

4.11 The Lahat Formation (also known as Lemat Formation): The age of this formation is late Mid-Eocene to Late Oligocene (Sardjono and Sardjito, 1989). The formation depicts the early rifting stage (Clure, 1991). This synrift deposit is as thick as 1,070m and depositional environments include scree, alluvial fan and fresh lake (lacustrine) to brackish lake (lacustrine) (Hutchison, 1996) and also includes granite wash. The granite wash is said to be the oldest rock of the Lahat Formation and sometimes called the Young Lemat (Hutchison, 1996).

4.12 The Talangakar Formation: The lower Talangakar Formation is known as the Gritsand Member and the upper Talangakar Formation is known as the Transition Member (e.g. Tamtomo et al., 1997). This Formation onlaps conformably on the Lahat Formation, but at the basin margins it lies unconformably on Lahat Formation and thereby extends farther beyond the depositional basin than the depositional limit of the Lahat Formation (Barber and Crow; Hutchison, 1996). It is Late Oligocene to Early Miocene in age. It has similar sediments as the Sihapas Group of the Central Sumatra but the sandstone units are thinner, finer grained and occur
in layers with claystones (Spruyt, 1956). In Clure (1991), the base of the sediments is depicted as an early transgressive fluvial event and the top depicts marine that shows the rise in sea level and the change from the rifting stage to the transgressive stage. Generally, this Formation is a “late syn-rift to post-rift” formation with thickness of about 610km and tend to be thicker where the formation beneath it (the Lahat Formation) is thickest (Hutchison, 1996). The Barisan Mountains, Tigapuluh Mountain and the Duabelas Mountains acts as the source for the sediment transported here. The formation is composed of “channel sandstones with silicified wood alternating with siltstones and carbonaceous shales”. Also present are mollusks, coal seams and tuffs; the environment of deposition is delta plain but it changes basinward to marginal marine and becomes euxinic in the troughs (Adiwidjaja and De Coster, 1973; Barber, 2000). The formation has a porosity of 15% - 30% and permeability of 5 Darcy (Tamtomo et al., 1997).

4.13 The Baturaja Limestone: The environment of deposition of the Baturaja Limestone is marine, it contains thick platform limestones with thin shales (included with it is glauconitic packstones and wackestones) and carbonate build-ups (“skeleton of packstones and coral-algal boundstones”). This reef build-up was drowned during the maximum transgressive stage and was later sealed by marine shales (De Smet, 1992; Barber, 2000). The Baturaja Limestone is early Miocene in age, formed adjacent to the Sunda Shelf and on a basement high (Clure, 1991). It is also called the Basal Telisa Limestone in Hutchison (1996). In Hartanto et al., (1991), the platform Limestone of the Baturaja Formation is 20 – 75m thick, the carbonate build-up and reef is 60 – 120m thick but in outcrop at the Garba Mountain part of the Barisan Mountain the formation is 520m in thickness (Hutchison, 1996). It has a “secondary” porosity of 18% - 38 % and permeability of 1 Darcy.
4.14 The Gumai Formation: The Gumai Formation is also known as the Telisa Formation (in e.g. Spruyt, 1956). The environment of deposit is marine and it downlaps onto the layer beneath it (the Baturaja Limestone) (Clure, 1991). The formation is Oligocene to Mid-Miocene in age and consists of grey foraminifera shales, siltstones with layers of glauconitic sandstones and tuff lenses that represent a “rapid widespread maximum transgression”. (E.g. Hartanto et al., 1991). The Gumai Formation is about 2,700m thick, though this thickness varies in the basins and gets thin at the basin margins and across basin highs. The formation also depicts the highest highstand transgression stage (Hartanto et al., 1991) and has a porosity of 20%. The presence of turbidites in this formations occurred as the sea level dropped (regression) and marks the end of the deposition of the formation in the middle Miocene (Hartanto et al., 1991).

4.15 The Airbenakat Formation: This formation is also called the Lower Palembang Formation, it was deposited at the end of the Transgression stage (the start of the Regression stage) from Mid-Miocene to Present (Spruyt, 1956), and consists of turbidite sandstones. Its thickness is about 1000 – 1500m (Hutchison, 1996) and the environment of deposition changes from deep marine to shallow marine (deltaic). The Airbenakat Formation is separated from the overlying formation (Muaraenim Formation) by coal beds (Hutchison, 1996). The Airbenakat formation has an average porosity of 25%.

4.16 The Muaraenim Formation: This formation is also known as the Middle Palembang Formation. It is of late Miocene to Pliocene in age and contains shallow marine land sandstones, mud and coals. The formation is about 750m thick at the south but becomes thin towards the north (Hutchison, 1996). This formation has an average porosity of about 30%.

4.17 The Kasai Formation: This formation forms a “local unconformity” on Muaraenim Formation. It is Pleistocene in age and is also known as the Upper Palembang Formation in
Courteney et al. (1990). It contains “tuffaceous sands, clays, conglomerates and tuffs with lignite and silicified wood”; it was formed during the deformation of the Barisan Mountain (Courteney et al., 1990; Barber and Crow, 2003).

Figure 10, stratigraphic column of the South Sumatra Basin. From e.g. De Coster (1974).
Chapter 5

5.1 RESULTS

In my modeling, I have constructed maps and cross sections to show the relationship between the Airbenakat Formation, Talangakar Formation and the basement rock. General maps of all formations in the basin have also being included to show the contacts between these formations and to have a general view of the basin. The modelings are represented in Figures 11, 12, 13, 14, 15, 16, 18 and 19. Figure 11 is a 3D block/stratigraphy/cross section of the Airbenakat Formation, the Talangakar Formation and the basement rock; different colors have been used for all strata of all formations for easy identification of the formations in the modeling. The figure represents the surfaces of the two formations and the basement rock constructed with the Rockwork Software and as deposited in the basin, it shows the relative thickness of each unit of the formations. The Airbenakat Formation which is younger than the Talangakar Formation onlaps on the Talangakar Formation; the basement rock is not well mapped or recognized on the map because only a small bedrock was recorded on the well logs. An area of erosion is noticed between the Airbenakat Formation and the Talangakar Formation. Also on the same map, the Talangakar Formation has been exposed at the surface that is uplifted to a basement high above the Airbenakat Formation. The Talangakar Formation also shows a voluminous thickness when compared to all other formations in the basin which could be seen in figures 16, 18 and 19. Figures 16 and 19 are maps which represent the strata of all eight formations in South Sumatra Basin while figure 18 is a cross section of all eight formations.

Figures 12, 13 and 14 are isopach maps of the two formations and the basement rock, the maps were constructed with Surfer 11 Software. The maps represent a plot of longitude, latitude and the depth of top and bases of the Airbenakat Formation, Talangakar Formation and the basement
rock respectively. The isopach maps of the three formations shows nearly same thickness towards the southwestern corner of the map that is they are clustered together and located at the southwest corner of the maps (figure 12, 13 and 14). The compaction or clustering of the wells to the southwestern corner is a record of the thickness in the basin or it could represent areas of uplift in the basin; the thicknesses shown on the three isopach maps thins out towards the north of the map. The thinning towards the north may be areas of lows in the basin. Figure 15 is a base map/contour map that shows the location of all oil wells; it is a plot of the longitude, latitude and the total elevation of all wells constructed with Rockwork Software. The difference between figures 12, 13, 14 and 15 is that figure 15 is a Rockworks Software plot of the longitude, latitude and the total driller elevation of the oil wells from each well logs. In figure 15, all wells are located at the southwest corner of the map except for two wells one of which is located at the northwest corner and another located close to the east of the map. Figure 16 is a 3D stratigraphy model of the surfaces of the entire eight formations that is it includes all formation of South Sumatra basin. The difference between figure 16 and 18 is that figure 18 represents a block 3D stratigraphy model and contact between all the formations. Figure 19 is a fence diagram that represents the stratigraphy interpolation between all formations of South Sumatra Basin. Figures 16, 18 and 19 also show the relative thickness of each unit of the entire formations of the basin. Figures 16, 18 and 19 have been included to show the relationship between the entire formations and to show it resemblance to the cross section (figure 17) from Hutchison (1996).
Figure 11 is a 3D block/stratigraphy map/anticlinal structure; it also shows the onlap and relationship between the Airbenakat Formation, Talangakar Formation and the basement rock. Diagram constructed with Rockworks Software.
Figure 12 shows the isopach map of the Airbenakat Formation. Constructed with Surfer 11 Software.
Figure 13 shows the isopach map of the Talangakar Formation. Map constructed with Surfer 11 Software.
Figure 14 shows the isopach map of the basement rock. Map constructed with Surfer 11 Software
Figure 15 shows the base map/contour lines, well locations and well depths. Map constructed with Rockworks Software.
Figure 16 shows the 3D stratigraphy model of all formation surfaces. Constructed using Rockworks Software.
Figure 17 shows the cross section of the South Sumatra basin. From Hutchison (1996).
Figure 18 shows block model/3D stratigraphy contact between all the formations constructed with the Rockworks Software.
Figure 19. Fence diagram shows the stratigraphy interpolation between all formations of South Sumatra Basin.
5.2 DISCUSSIONS

Basement rocks as described by Petford and McCaffrey (2003) are “any igneous or metamorphic rocks unconformably overlain by a sedimentary sequence”. This characteristics describe the basement rocks of the Sumatra Basin (Central and South Sumatra, etc.) (Petford and McCaffrey, 2003). Some researchers (e.g. Landes et al, 1996) mentioned that basement rocks generally could be a prolific reservoir particularly when there are lots of faults and fractures in the basement rock (figure 11 of my modeling shows the uplifted Talangakar Formation). They added that the reason could be that the basement rock is at a higher elevation than the surrounding sediment. This could be the reason the basement rock in South Sumatra serves as a reservoir in the basin because it was mentioned in Barber and Crow (2005) that there were reoccurrence and uplift of the basement rock or sedimentary basin inversion, basement fault reactivation, compression and folding in South Sumatra during the Pleistocene period. Landes et al (1960) also indicated in their report that for a basement rock to serve as an oil reservoir it must have gone through weathering, solution, leaching, fracturing and faulting. The basement rocks of South Sumatra serves as a reservoir in this region because it has undergone basement faulting which may have created the path way for hydrocarbons to migrate to the basement rock.

Another researcher (Gutmanis and Batchelor, 2010) highlighted the major controlling factors in hydrocarbon distribution in basement rocks as:

1. Lithology – they mentioned that this can be an important factor in hydrocarbon distribution particularly when the basement rock is igneous in nature because igneous rocks are blocky, they have good fracture connectivity, and they are massive and homogenous in nature unlike metamorphic rocks which are layered.
2. The deformation history of the basement rock that is the degree of deformation with faults and its closeness to faults and fault zones.

3. Secondary porosity in basement rock through the dissolution of minerals in fractures and matrix from secondary alteration by hydrothermal and meteoric activities.

4. Tectonic and fracture history of the basement rock, this may happen if the current stress level of the area affects the youngest structure.

Furthermore, from the controlling factors mentioned above, the basin inversion history of the basin may have played a huge role in hydrocarbon distribution in the basin. Turner and Williams (2004) defined basin inversion as the shortening of previously existing extensional basins caused by compression of existing faults and fracture which is one of the major tectonic phases that formed South Sumatra basin. This may be possible because from the result shown above and from sedimentary basin inversion described by Turner and Williams (2004), the change from normal fault to reverse faults and the uplifting of a “low lying basin areas’ to high areas (figure 11) are some of the characteristics of basin inversion exhibited by South Sumatra basin.

In addition to the above, the control on oil distribution in South Sumatra may also be due to the uplifted basin because oil could easily migrate along faults zones from anticlines to other low areas in the basin and because most of the structural oil traps (anticlines) were formed during the compression of the basement rock in the Miocene period. The anticlines trend in a northwest to southeast direction and became more noticeable between 2Ma- 3Ma (Courteney et al, 1990). The combination of stratigraphy traps (pinch-outs and carbonate buildups) and structural traps (faults and anticlines) have also contributed to the oils trapped in the basin (Sardjito et al, 1991). The oil traps like stratigraphy pinch outs and structural faults will aid or control oil distributions in the basin. The Talangakar Formation and the Lahat Formation which are the two main source rocks
in the basin lye unconformably on the basement rock and together with compressional forces, thermal heat, pressure and because of the faults zones will aid in easy flow of oils into fractured and weathered basement rock. And from history, the basement rock of South Sumattra have undergone weathering, erosion, fracturing and faulting and this may create a secondary porosity in the rock for hydrocarbon passage to the basement rock. In Hutchison (1996)’s cross section of the basin (figure 17), he mentioned that there are lots of faults in the basin. In my modeling of the general map of all formations in the basin, figures 11 and 18 shows some resemblance to the cross section (figure 17) in Hutchison (1996) except that faults are not shown in the model I constructed with Rockworks software.

Although faults and fault zones were not visible on well logs analyzed and in most of the figures I constructed but other useful informations were analyzed. I noticed that most of the old and large oil producing fields in South Sumatra basin were located at the South Palembang sub-basin, some of which have been abandoned because they are dry or not producing. The oil fields of South Palembang sub-basin are larger and older than the recent oil fields in Jambi sub-basin.

The new and recent recognition of hydrocarbon accumulations in Jambi sub-basin may be due to its proximity to the Sunda Plates (Figure 9 in chapter 3 shows the proximity of the Jambi sub-basin to the Sunda Shelf Plate and as mentioned in Doust and Noble (2008)) and the reactivated faults due to basement compressional forces. An example of measurement of fracture and fault stress of an oil field (the Suban field) in South Sumatra that created spaces for permeability and interconnectivity of pore spaces around Jambi sub-basin is shown below in figure 20 (Hennings et al, 2012 ). The figure is a 3D structural model and seismic interpretation of the southwestern domain of Southern Sumatra, the figure also shows faults along the crest of the anticline. And
because reactivated faults may become “conduits for hydrocarbon leakage” to other areas in a basin; the South Sumatra basin as shown in figure 9 has some basement faults.

Figure 20 shows a 3D structural model and seismic interpretation of the southwestern domain of the Southern Sumatra with faults along the crest of the anticline. From Hennings et al, (2012).

In addition to the above and from the well log data analyzed, only few oil fields are present in Jambi sub-basin; almost all oil fields are new discoveries and are all oil producers while most of the oil fields in Palembang sub-basin are old, some have been abandoned or suspended because they were not successful and are not producing. Some Wildcat Wells (i.e. an exploratory well drilled a mile or more from existing production well) are still producing oils and some are not,
the producing wells have casing in them while the dry wells have no casing as shown on the well log data. Out of all the four hundred and ten wells looked at, one hundred and seventy four wells are not producing that is they have been abandoned because they were not successful.

More so, within the Jambi sub-basin the Airbenakat sandstones which represents a regressive sequence in the basin contains many sandstones which “crop out and sub-crop out” along the edges of the Sunda landmass and to some degree may have oil present in some places (Clure 2005). The oil shows in the out crops however explains why the Jambi trough is a recent focus for hydrocarbon in South Sumatra Basin and because the Jambi trough is proximal to the Sunda landmass and because the sands are frequently exposed to meteoric waters. The meteoric water will dissolve minerals in fractures and matrix of the basement rock thereby creating secondary porosity in the basement rock, basement faults will then serve as channels for hydrocarbon leakage to other areas in the basin. The oil fields in South Sumatra have been traced to oil seeps from the anticlinal structures (Zeliff et al, 1985), the anticlines may have also contributed to the distribution of oil and gas in the basin (Ford, 1985). The presence or absence of oil in some wells may however be related to the controlling factors mentioned above and the sedimentary basin inversion process (figure 11 shows the anticline structure of South Sumatra basin). That is some wells may be close to fault and fault zones and oil could migrate easily through fractured zones in the rock which could result in accumulation of oil in some areas and absence of oil in some (The onlap of Airbenakat Formation in figure 11 may be faulted but not shown on map).

During the early formation of South Sumatra basin, the grabens formed in late Eocene to early Oligocene subsided and from studies by some researchers, half grabens could be important oil and gas prospect particularly when they contain source rocks and reservoir rocks. Therefore there is a possibility that that oil from the overlying Talangakar Formation and Lahat Formation
migrated into the basement rock because the two formations overlie on the basement rock. This may also be the channel which linked the basement rock to the oil produced from the overlying source rocks which is then distributed to other areas in the basin.

In other words, the oil trapped in the basement rock of South Sumatra may be wholly or partially related to the onlap of tertiary sediment on the basement rock and the fault in the basin (Figure 11 shows onlap of the Airbenakat on the Talangakar Formation and the basement rock). Because onlap surfaces are associated with marine transgression, the Airbenakat Formation which represents the onlap surface here is evidence of transition from a deep marine transgression to a shallow marine and it marks the end of the transgressive stage in South Sumatra basin.

The following studies by some researchers could give some valuable insight and could describe the various ways by which hydrocarbons in a basin can migrate and be distributed with different models. This however could be related to the processes of inversion and all other tectonic processes that formed the South Sumatra basin. In Beauchamp et al. (1996), they mentioned that “remigration and redistribution” of hydrocarbon into structures formed from reactivation of pre-existing faults during the process of rifting can be a result of the uplifted and inverted hydrocarbon bearing rifts. Adding that a better knowledge of the geometric structures formed during reactivation of the synrift faults will be beneficial because such structures formed could be or serve as a “potential” trap for reasonable amounts of hydrocarbons. Another point highlighted in Beauchamp et al. (1996) is that the reactivated normal synrift faults could invert a formerly existing graben to an anticline structures.

The recent discovery of hydrocarbon accumulation in Jambi trough may be related to inversion process because as reported in e.g. Jensen and Schmidt (1993) that source rocks at a “sub-mature depth” may become mature prior to their inversion. Piggott and Lines (1991) stated in their
report that gas accumulation at high temperature/high pressure may release oil by the process of retrograde condensation. Cramer et al. (2002) described that a reduction in pressure after exposure of a buried rock can result in accumulation of “basin-centered gas” by separation of methane from formation waters. Bourne et al. (2001) pointed out in their own report that hydrocarbon prospectivity can be due to brittleness of a reservoir and particularly when they are carbonates and this could increase pore spaces for easy hydrocarbon migration. They also mentioned that fractures that occur naturally can act as a great and permeable fluid channels for hydrocarbons because they have a striking impact on the performance of reservoirs. Carr (1999) indicated that the maturity of source rock is decreased during the process of “endothermic volume expansion reactions” and in the process of “fluid overpressure”. He stated further that keeping the chemical equilibrium and releasing the fluid pressure will stop the decrease in the maturity of the source rock which will still lead to continued hydrocarbon production. He gave his example referring to the late dry gas of the Norwegian North Sea. Mostly all models by the researchers mentioned above show that all wall rocks adjacent to faults areas undergoing reactivation and fracturing have the ability to improve reservoir permeability.

Macgregor (1995) mentioned that a look at most inverted basins of the world shows that locally inverted basins like Central Sumatra and Malay basin have a huge success rate of hydrocarbon exploration when compared to uninverted rifts basins but that the basins may have smaller oil field sizes. He added that this in effect is due to the simple anticline traps formed during the inversion process and without a concurrent break in the oil seal or loss of the structure of that area.

The control on hydrocarbon production and distribution in South Sumatra, and generally in Indonesian Basin, may be due to various factors such as – sedimentary basin inversion, the
maturity and facies of the source rocks, the differences in reservoir facies, and the type and
development of structural/stratigraphy traps and seals (either intraformational or regional). The
changes in facies (from non-marine to marine sediments) in relation to the environment together
with the oil sourced from lacustrine Lahat Formation and terrestrial Talangakar Formation have
played a huge role in the sediment infill of South Sumatra basin. The oil trapped in the basement
rock may have migrated to the basement rock due to permeability of the basement rock after
brittle fracturing of the basement rock. This may be the reason the basement rock serves as a
reservoir in the basin and because the depth of the basement rock has been uplifted to a higher
elevation than the surrounding younger sediments so oil could migrate easily into the basement
rock through oil seeps. More so, the unconformity between the basement rock and the overlying
formations may have created a path way for hydrocarbons to migrate into basement reservoirs
and other reservoirs in the basin. Because it may have connected the source rocks and reservoir
rocks of the Lahat Formation and the Talangakar Formation both of this Formation may lie on
opposite sides of the unconformity (Figure 17 shows the cross section of the basin from
Hutchison, 1996). In addition to the above, the unconformity surface which separates the
overlying Lahat Formation and Talangakar Formation from the basement rock may have
undergone weathering, erosion and leaching. And because the basement rock is igneous rock so
there is a possibility of good fluid connectivity when the igneous rocks are fractured during
basement faulting. This may result in high porosity of the basement rock and permeability of
hydrocarbons into the basement rocks.

Although the sedimentary basin inversion process may have contributed in a way to the
exploration of hydrocarbons in the basin, however, the production and distribution of
hydrocarbons in the basin may depend wholly or partially on the quantity of hydrocarbons
available and on post migration (secondary and tertiary migration of hydrocarbons) after post inversion process.

The major three tectonic process involved in the formation of South Sumatra basin are: 1) the extension of north trending grabens filed with Eocene to early Miocene deposits, 2) late normal faulting and 3) basement compression forces, basin inversion, and change from normal fault to reverse fault. The anticline structures are the dominant and major structural traps in South Sumatra basin. Figure 11 shows this anticline structure with the Talangakar Formation (one of the two source rock) exhumed and on basement high in the cross section.

5.3 CONCLUSIONS

In conclusion, the link between the basement rock and oil produced and distributed in the basin may be due to the uplifted basin as shown in figures 11, 16, 18 and 19. Because the basement rock together with the source rock of the Talangakar Formation has been uplifted to a basement high, this will then create a path way for easy hydrocarbon migration to the basement rock. Also from history, the basement rock has undergone faulting; this will make the rocks to become brittle and fractured and thereby creating pores spaces and pore spaces are good for fluid connectivity.

Above all, the models constructed with Rockwork Software may show an uplifted basin but to have an in-depth knowledge of the relationship between the basement rock and oil produced and distributed in the basin, other models such as seismic data analysis and petrophysical analysis of the basin amongst others can be comprehensive and provide more insight to determine what quantity of hydrocarbons is generated or can be generated from the basement reservoir.
## APPENDIX

**TABLE 1**

<table>
<thead>
<tr>
<th>Well Name</th>
<th>Total Depth</th>
<th>Hydrocarbon Production</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meruap 2</td>
<td>1601.1</td>
<td>Oil</td>
</tr>
<tr>
<td>Menggala Selatan 1</td>
<td>859</td>
<td>Dry</td>
</tr>
<tr>
<td>Meruap 4</td>
<td>1602.9</td>
<td>Dry</td>
</tr>
<tr>
<td>Punjung 1</td>
<td>1688.6</td>
<td>Oil</td>
</tr>
<tr>
<td>Rukam 1</td>
<td>3076.3</td>
<td>Oil</td>
</tr>
<tr>
<td>Tambesi Bay 1</td>
<td>2686.8</td>
<td>Oil</td>
</tr>
<tr>
<td>Terap 1</td>
<td>1828.8</td>
<td>Oil</td>
</tr>
<tr>
<td>Muara Bualian 1</td>
<td>2020</td>
<td>Dry</td>
</tr>
<tr>
<td>Plajawan 1</td>
<td>2643</td>
<td>Dry</td>
</tr>
<tr>
<td>Sungai Medak 1</td>
<td>1952</td>
<td>Dry</td>
</tr>
<tr>
<td>Siarak 2</td>
<td>567</td>
<td>Oil</td>
</tr>
<tr>
<td>S.E. Babat 1</td>
<td>796.4</td>
<td>Oil</td>
</tr>
<tr>
<td>Sembatu 1</td>
<td>2574.3</td>
<td>Oil</td>
</tr>
<tr>
<td>Sembatu 2</td>
<td>2412.5</td>
<td>Oil</td>
</tr>
<tr>
<td>Serdang 1</td>
<td>939.4</td>
<td>Oil</td>
</tr>
<tr>
<td>Semi 1</td>
<td>985.1</td>
<td>Dry</td>
</tr>
<tr>
<td>Sialan 1</td>
<td>1130.2</td>
<td>Dry</td>
</tr>
<tr>
<td>Rimbo 1</td>
<td>626.4</td>
<td>Dry</td>
</tr>
<tr>
<td>Rombongin 1</td>
<td>1896.2</td>
<td>Dry</td>
</tr>
</tbody>
</table>

Table 1 shows examples of dry and oil producing fields.
<table>
<thead>
<tr>
<th>Rn</th>
<th>Panel</th>
<th>Cartridge</th>
<th>Sone</th>
<th>Run and Memory Panel</th>
<th>G R</th>
<th>Tape Recorder</th>
<th>Caliper</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>871</td>
<td>1715</td>
<td>1721</td>
<td>935</td>
<td>1755</td>
<td>119</td>
<td>RA</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Rn</th>
<th>Time Constant</th>
<th>Stand-off</th>
<th>Converting Device</th>
<th>Zero cord adjusted at</th>
<th>Rift averaged</th>
<th>Note peak detection</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1800 FPF</td>
<td>1.5</td>
<td>RA</td>
<td>YES</td>
<td>NA</td>
<td>NA</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Rn</th>
<th>Alt. Scale</th>
<th>Background CPS</th>
<th>Total CPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>165</td>
<td>SF</td>
<td>SF</td>
</tr>
</tbody>
</table>

**REMARKS**

- Dabdric 8"-10.1 SPACER
- SF GRID AT 474 and 580 ft
- Dabdric Spacer guards at 1814-1890 and 1805-1831 ft. USE REPEAT SECTION VALUE.
<table>
<thead>
<tr>
<th>SPONTANEOUS POTENTIAL</th>
<th>RESISTIVITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>millivolts</td>
<td>ohms - m</td>
</tr>
<tr>
<td>10</td>
<td>DEEP INDUCTION $R_{d0}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GAMMA RAY</th>
<th>INTERVAL TRANSIT TIME $\Delta t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>api units</td>
<td>microsecond per foot</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Depths</th>
<th>1 x 1000</th>
<th>10</th>
<th>100</th>
<th>1000</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TTI</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 m sec</td>
</tr>
<tr>
<td>1 m sec</td>
</tr>
</tbody>
</table>
References


